Review Article

SUSTAINING POLLINATOR DIVERSITY: CONSERVATION, CHALLENGES, AND SOLUTIONS FOR ECOSYSTEM HEALTH

ABSTRACT

Pollinators, encompassing a diverse array of insects and vertebrates, play a pivotal role in maintaining biodiversity and ecosystem health. This paper explores the significance of pollinators in global ecosystems, emphasizing their indispensable contribution to crop production, nutritional diversity, and the overall quality of human diets. However, current rates of species extinction, primarily driven by human impacts such as pesticide use, habitat loss, and climate change, pose grave threats to pollinator populations worldwide. Pesticides, particularly neonicotinoids, have been identified as a significant cause of bee colony losses, leading to issues like Colony Collapse Disorder (CCD) and substantial declines in bee species. Additionally, factors such as habitat degradation, pathogens, and heavy metal pollution further exacerbate the decline of pollinators. Various conservation strategies are proposed to address these challenges, including habitat restoration, sustainable farming practices, and minimizing pesticide use through integrated pest management. Furthermore, the importance of genetically modified crops in mitigating adverse effects on pollinators is discussed, highlighting the need for evidence-based approaches to ensure the safety of these technologies. Raising awareness about the importance of pollinators and promoting sustainable agricultural practices are essential for safeguarding pollinator populations and ensuring global food security. Integrated Pest and Pollinator Management (IPPM) emerges as a promising approach to harmonize pest control with preserving beneficial species, offering a holistic strategy for sustainable crop production. Overall, concerted efforts at the individual, community, and policy levels are imperative to address the multifaceted challenges facing pollinators and to secure the resilience of ecosystems worldwide.

Keywords: Colony collapse disorder; conservation; integrated pest and pollinator management; pesticide impact; pollinator diversity; Varroa mite.

1. INTRODUCTION

Biodiversity in pollinators and pollination systems is remarkably diverse, encompassing over 25,000 to 30,000 bee species of Apidae family along with various other insects, such as beetles, moths, wasps, butterflies, and flies. Additionally, vertebrate pollinators, including birds, bats, rodents, and monkeys (Table 1). Tropical and Mountain ~~Ecosystems~~ ecosystems mainly depend on pollinators. About 80 % of flowering plant species rely on animal pollination, predominantly by insects [1] (Table 2). In tropical forests, for instance, insects may account for up to 95 % of the pollination of canopy trees, while vertebrates, including bats and various taxa, contribute to the pollination of 20 to 25 % of understory and subcanopy plants [2]. Pollination is vital for human livelihoods, especially in agro-ecosystems where pollinators are indispensable for orchard, horticultural, and forage

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production. Birds, bats, and bees impact 35 % of global crop production, enhancing yields for 87 major food crops and various plant-derived medicines [3]. Beyond abundance, pollination significantly contributes to the nutritional diversity, vitamin sufficiency, and overall quality of human diets [4]. To adapt to changing climates, optimal crop production requires a diverse set of pollinators, potentially extending beyond managed honeybees. Current rates of species extinction, driven by human impacts, are estimated to be 100 to 1,000 times higher than the natural norm. In the foreseeable future, the majority of biodiversity loss is anticipated to be among insects, with approximately 40% of invertebrate pollinator species, particularly butterflies and bees, followed by vertebrate pollinators, with approximately 16.5% facing the risk of extinction. Of these, human-induced pesticide use, changes in land use, loss of habitat, widespread adoption of intensive agricultural practices, introduction of foreign species, and monocultures~~, and~~ have resulted in extensive loss of pollinators.

Pesticides emerged as the main cause behind the demise of bee colonies, responsible for annual losses ranging from 23% to over 50% of colonies. The indiscriminate use of pesticides, particularly neonicotinoids, ~~which is~~ a group of systemic insecticides, poses a significant threat to insect pollinators, beneficial insects, and overall insect populations, leading to issues like Colony Collapse Disorder (CCD), habitat destruction, and substantial declines in bee species, with additional concerns arising from harmful effects induced by fertilizers and other chemical substances in various ecosystems [5]. Most farmers are aware of the harmful effects of pesticides on the environment and other species, but the issue lies in a lack of proper care. In Gimbo District, a beekeeper lost ten bee colonies due to improper application of pesticides by the farmer. It is a major challenge for beekeepers [6]. Beekeepers observed more colony loss particularly in the early 2000s, with some losses attributed to ~~Colony Collapse Disorder (~~CCD~~)~~ which is a phenomenon marked by the sudden disappearance of numerous worker bees, leaving their queen behind [7]. The assessment of pesticide residues in honeybees, nectar, and pollen indicates that some residues may currently be harmful to bees. Honeybees are exposed to significant doses, reaching up to 50–100% of the lethal dose for fipronil and imidacloprid (96.66% and 59.77%, respectively), 10–50% of the lethal dose for permethrin (10.87%) through oral exposure. Moderate risk of sublethal effects (1-10 %) for specific organophosphate, pyrethroid, and carbamate pesticides. For other pesticides, the risk of harm through oral exposure is below 1% [8].

Monoculture practices contribute to the overuse of pesticides, loss of foraging resources for native pollinators, increased stress and nutritional deficiencies in honey bees, and the potential for mass colony losses during long-distance transportation for crop pollination [9]. Varroa mite damage bees by feeding on their body fluids, transmitting viruses, and weakening the bee's immune system. These parasitic mites primarily target honey bee larvae and pupae, causing deformities and often leading to the premature death of affected individuals. Additionally, these mites can reduce the overall lifespan of adult bees and weaken entire colonies [10]. The mites also contribute to the spread of various bee viruses, further effecting the health and survival of bee populations [11]. Pathogens, particularly viral diseases like the Deformed Wing ~~virus~~Virus (DWV), Black Queen Cell Virus (BQCV), and Acute Bee Paralysis Virus (ABPV) contribute to the decline of pollinator populations, especially in honey bees and bumble bees, as they interact with factors such as poor nutrition and pesticide exposure, with evidence suggesting spillover from managed bees to wild populations. The presence of transgenic crops~~,~~ has the potential to directly impact pollinators,

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with transgenic proteins expressed in pollen and nectar potentially causing toxicity and neural disturbances.~~,~~ ~~although~~ Although some observations suggest that certain Bt-toxins may be non-toxic to Hymenopterans and their colonies.

The decline in pollinators is linked to metal pollution, particularly heavy metals like cadmium, copper, iron, manganese, and zinc, along with adverse effects from industrial discharge, sewage, and agricultural runoff, while light pollution from urbanization negatively affects nocturnal pollinators, impacting their physiology, behaviour, and communication [12]. Climate change, marked by rising temperatures, altered rainfall patterns, and increased frequency of extreme events, has multifaceted impacts on organisms, affecting the metabolism and life cycles of plants and pollinators, leading to shifts in flowering times, disruptions in pollinator services, and potential declines in biodiversity, with consequential threats to global food security and nutritional balance, as well as the need for the development and implementation of bioindicators, such as dragonflies, to monitor and assess ecological changes in aquatic ecosystems [13]. Bees, when ~~exposure~~ exposed to electromagnetic radiation from cordless telephones, resulted in heightened agility, increased swarming drive, and ~~a~~ lack of winter clustering, while colonies exposed to DECT cordless telephone base station fields exhibited slower weight and area development, along with significant differences in the homing ability of bees exposed to the field compared to those that were not [14]. To address this issue, initiatives must focus on habitat restoration, advocating for sustainable farming practices, and minimizing pesticide use through integrated pest management. By integrating research, community engagement, and policy advocacy, comprehensive conservation actions can safeguard the future of pollinators and the ecosystems they support.

2. DIVERSITY OF POLLINATORS

Diversity of pollinators includes Bumble bee, Wasp, Stingless bee, Pierid butterfly, Honey bee, Eye gnats, Hawk moth, House fly, ~~and~~ Blow fly, etc. (Fig 1.). It plays a crucial role in maintaining biodiversity and ecosystem health and they exhibit a remarkable diversity in terms of their characteristics, behavior, and interaction with plants. The co-evolutionary relationship between flowering plants and their pollinators commenced approximately 225 million years ago.

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Fig 1. Diversity of pollinators. (A) Bumble bee (B) Wasp (C) Stingless bee (D) Pierid butterfly (E) Honey bee (F) Eye gnats (G) Hawk moth (H) House fly (I) Blow fly

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Figure 1(F) is not clear
Try to give images where the pollinators are visiting flowers.
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Table 1. Insect Pollinators and Their Pollination Rates

Order	Common name	Mode of pollination	% of pollination
Hymenoptera	Honeybees	Melittophily	56.5%
	Wasps	Sphecophily	5%
Coleoptera	Beetles	Cantharophily	5%
Diptera	Flies	Myophily	19%
Lepidoptera	Butterflies and moths	Phalaenophily	4%
Passerformes	Birds	Ornithophily	4%
Chiroptera	Bats	Chiropterophily	6.5 %

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Table 2. Percent increase in the yield of crops due to pollinators

Crop	Insect pest	Yield loss (%)	Yield attributes	% increase in the yield due to pollinators	Reference
Tomato	Fruit borer, RKN	24-65	Fruit set	8.3-27.40	Abrol, 2022
Chilli	Thrips, Mites, RKN	12-90	Fruit set	73-84	Yourstone *et al.*, 2021
Onion			Seed set	90.47	Kumar *et al.*, 1989
Okra	Fruit borer, Leafhopper, Whitefly, Shoot and fruit borer	22-66	Fruit set	73-84	Perera and Karunaratne, 2019
Brinjal	Fruit and shoot borer, RKN	11-93	Seed yield	35-67	Abrol, 2022
Cabbage	DBM, Borers, Leafwebber	17-99	Seed yield	100-300	
Cucurbits	Fruit fly	20-100	Fruit weight and fruit set	32.50-4800	
Apple	Codling moth and apple maggot	10-40	Fruit set and fruit weight	15-20	Partap 1999a
Peach	Oriental fruit moth and peach twig borer	10-35		22-44	Partap *et al.*, 2000
Plum	plum curculio and aphids	15-30		13-39	Partap *et al.*, 2000
Citrus	Fruit sucking moth	10–55		24-35	Partap, 2000

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Comment [Ma10]: Why these two columns are here? This table is dealing with yield increase due to pollination, not yield loss due to insect pests. It seems irrelevant here. The Table caption also not signifies their presence in this table.

Strawberry	spider mites and strawberry root weevils	15-40		112-48	Partap, 2000
Mango	Hopper	20-100	Fruit productivity	3-5	Partap 1999b
	Mealybug	50-90			
	Fruit fly	10-80			
Papaya	Mealybug	8-33		5-10	
Litchi	Litchi bug and fruit borers	10-25		20-25	
Grapes	Berry moth and mealybugs	10-20		10-20	
Pear	psylla and codling moth	10-20		10-15	
Guava	Guava Fruit fly, bark borer and fruit borer	3–38		5-10	
Almond	Orangeworm and peach twig borer	10-30	Fruit productivity	50-75	Abrol, 2009
Cumin	Aphids and seed bug	10-20	Seed yield and quality	40.03	Meena *et al.*, 2018
Coriander	Aphids and seed bug	10-20	Germination Seed set	70.25-72.50 64.76-65.94	Kumar and Jaiswal, 2012
Fennel	Aphid	10-20	Seed set	70.04	Kumar and Singh, 2017
Bell pepper	thrips and aphids	15-35	Fruit yield	82.35	Devi *et al.*, 2019
Cardamom	Thrips and shoot borers	20-40	Fruit set	21-37	
Gingelly	Sesame webworm and leaf roller	10-30	Seed set	Upto 25	
Sunflower	Sunflower moth and seed weevil	10-35	Seed yield	43	Chambó *et al.*, 2011

2.1 Hymenoptera (Melittophily)

Hymenopteran~~s~~ ~~are~~ is a diverse order of insects that includes important pollinators, primarily bees. ~~Among these, bees~~ Bees are especially critical as pollinators, ensuring the fertilization of numerous crops, including fruits, vegetables, and oilseeds. For instance, in almond orchards, honeybee colonies are often introduced to enhance pollination, significantly boosting almond yields [15]. *Apis mellifera* Linnaeus, owing to its highly social nature, has become a dominant species in global commercial pollination. However, the importance of non-*Apis* bees, both wild and domesticated, in pollinating various crops is being increasingly recognized. Non-*Apis* species, such as solitary bees used in orchard crop pollination, bumble bees used primarily for greenhouse tomato pollination, *Megachile* used in alfalfa pollination, and stingless bees used in coffee and other crop pollination. Hymenopterans also act as parasitoids~~, particularly from the Braconidae family~~, which play a crucial role in natural pest control in various crop ecosystems that reduce the need for chemical pesticides [16].

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Additionally, ants, particularly leafcutter ants, play a vital role in nutrient cycling by breaking down organic matter and returning nutrients to the soil, thus maintaining soil fertility and ecosystem health [17].

Bees are covered in branched and feathery hairs called setae, which create a dense covering known as pubescence. These hairs are excellent at trapping pollen grains. As bees move from flower to flower, pollen grains adhere to their body hairs, allowing for efficient pollen transfer [18]. Certain species of bees, such as honey bees and bumblebees, have a specialized structure called pollen basket or corbicula on their hind legs, which is used to carry and transport pollen back to the hive. Some bees have specialized hairs on their legs or body, often referred to as pollen brushes or scopal hairs, which help in collecting and transporting pollen. In addition to the pollen basket, honey bees have a specialized structure called a pollen comb located on their hind legs. This structure aids in grooming and collecting pollen. It has specialized mouthparts adapted for collecting nectar and pollen from flowers. They have a long proboscis that allows them to reach deep into flowers to access nectar. Some bees also have specialized structures on their mouthparts, such as labial palps, which aid in grooming and manipulating pollen [19].

2.2 Diptera (Myophily)

Dipterans, commonly known as flies, ~~that~~ serve as lesser-known but nonetheless significant pollinators. These are the second most common group visiting flowers, being seen around 72 ~~per cent~~ %of crops. Among the flies, the hoverflies (Syrphidae family) were the most frequent non-bee visitors, visiting more than half of the different crop plants, including many fruits, vegetables, and oilseed crops. Their hairy bodies inadvertently collect and transfer pollen between flowers as they seek nourishment. Another group of flies, the blow flies in the Calliphoridae family, also made significant visit to flowers [20]. Additionally, families such as Empididae (dance flies), Bombyliidae (bee flies), Tachinidae, and Anthomyiidae also contribute to pollination by visiting flowers for sustenance. While flies may not possess the same level of specialization as bees in pollination, their diverse interactions with flowering plants add to the overall complexity of ecological systems. Apart from pollinators, fruit flies are major pests in fruit and vegetable crops, causing significant economic losses worldwide. Leaf miner flies are important pests in various crops, such as tomatoes, beans, and citrus [21].

Dipteran pollinators have compact bodies, which allow them to move easily among flowers. Most of them are relatively small to medium-sized, facilitating their entry into flowers [22]. These pollinators have legs adapted for perching on flowers, allowing them to feed efficiently. Some species have specialized hairs on their legs that aid in pollen collection and transportation. They often have short, clubbed antennae, which help to navigate and locate flowers. In general, irrespective of the different size of the pollinators, pollen is loaded on the posterior part of the head or behind the eyes and anterior part of the thorax [23].

2.3 Lepidoptera (Phalaenophily)

Lepidopteran, which includes butterflies and moths, play a notable role in pollination~~,~~ of around 54 ~~per cent~~% of crops, contributing to the reproductive success of various flowering plants. They pollinate numerous food crops such as tomatoes, strawberries, and apples, enhancing genetic diversity and resilience in plants. The presence of diverse lepidopteran species in an ecosystem is an indicator of environmental health. They are sensitive to changes in habitat quality, making them valuable bioindicators for monitoring ecosystem changes and guiding conservation efforts [24].

Unlike bees, lepidopterans do not actively collect pollen for food; instead, pollen transfer occurs incidentally as they feed on nectar [25]. They are attracted to flowers primarily for nectar, which serves as their main energy source. As they feed, their bodies encountered the reproductive structures of the flowers, leading to unintentional pollen transfer. The structure of lepidopteran mouthparts~~,~~ possess a proboscis, a long, straw-like structure adapted for sipping nectar, allows them to pick up and carry pollen from one flower to another. This contributes to the fertilization of plants and the production of seeds. The nectar-feeding butterflies had higher pollination efficiency than the nectar- and pollen-feeding honey bees. Butterflies usually have straight antennae with clubbed ends, while moth antennae can vary from feathery to thread-like, aiding in the detection of floral scents [26]. Certain butterflies may preferentially visit specific flower types, leading to co-evolutionary adaptation between the insects and the plants. ~~and these~~Butterflies are diurnal or daytime pollinators, while moths depend~~ing~~ on the plant species that may be active during the day or night. This temporal variation can influence the types of plants they pollinate. However, using ~~Minimize~~ artificial light at night~~, as excessive lighting~~ can disrupt the behaviour of nocturnal pollinators and affect their populations. That's why we need to minimize the excessive use of artificial light at night -[27].

2.4 Coleoptera (Cantharophily)

Beetles are one of the most abundant groups of insects, and many species actively participate in pollination of around 51 ~~per cent~~% ~~of~~ crops. They are primary pollinators for many ancient plant lineages, including magnolias, water lilies, and some cycads [28]. These plants have evolved to attract beetles specifically through their floral structures and scents. Many beetles are adapting at burrowing into flowers or climbing onto them, which encountered reproductive structures. With strong mouthparts and diverse body shapes, beetles often access flowers in search of nectar or/and~~,~~ pollen and transfer the pollen thereby. Certain beetles are active at night and pollinate nocturnal flowers, which are often large and fragrant to attract these insects. Unlike some other beetles, *Chrysolina aurata*~~,~~ ~~have~~ has specialized surfaces for pollen adherence.~~,~~ ~~t~~These beetles rely on a fluid on their mouthparts to help the pollen stick to the bristles. Staphylinidae beetles have been identified as potential or conclusive pollinators for 56 plant species, primarily in monocots and magnoliids [29].

Beetles commonly visit large, bowl-shaped flowers, where they may feed on nectar or consume pollen. While less responsive to flower colours, beetles are often attracted to strong scents emitted by certain flowers [30]. Some beetles are generalist feeders, while others exhibit specialization in feeding on specific plants, fostering plant-beetle co-evolution. Beetles may crawl or walk on flowers, facilitating pollen transfer between floral structures. Certain beetle species are active at night, contributing to nocturnal pollination processes [31]. Beetles, known for their longevity, may spend extended periods on flowers, increasing the chances of successful pollination. Beetles as pollinators are widespread, adapting to diverse ecosystems, including tropical rainforests, deserts, and temperate regions. Understanding the role of beetles as pollinators is crucial for conservation efforts, as their presence contributes to the overall biodiversity and health of ecosystems.

2.5 Birds (Ornithophily)

Hummingbirds, primarily inhabiting the Americas, are renowned for their exceptional hovering capabilities and slender bills adapted for sipping nectar. With their rapid wing beats and unique ability to sustain mid-air positions, hummingbirds play a crucial role in pollination [32]. These avian pollinators are particularly drawn to tubular, brightly coloured flowers, and as they feed on nectar, they inadvertently transfer pollen from one bloom to another, facilitating cross-pollination and contributing to the reproductive success of various flowering plants. In regions where hummingbirds are absent, the ecological role of pollination is often fulfilled by sunbirds, found in Africa, Asia, and Australia. Sunbirds, characterized by iridescent plumage and long, slender bills, mirror the hovering feeding behavior of hummingbirds and serve as vital pollinators in tropical and subtropical ecosystems [33].

2.6 Bats (Chiropterophily)

Bats, particularly in tropical regions, emerge as a crucial nocturnal pollinator with adaptations such as echolocation and keen olfactory senses~~,~~. ~~bats~~ Bats navigate in the dark and efficiently pollinate night-blooming flowers, enhancing the genetic diversity and survival of numerous plant species [34]. Bats have a better memory in search of food compared to bees. Nectar-feeding bats can remember up to 40 different locations where they find food, making it easier for them to navigate and forage in the dark tropical environments during the night. These diverse avian and mammalian pollinators collectively highlight the intricate web of ecological interactions that sustains plant biodiversity across different geographical regions.

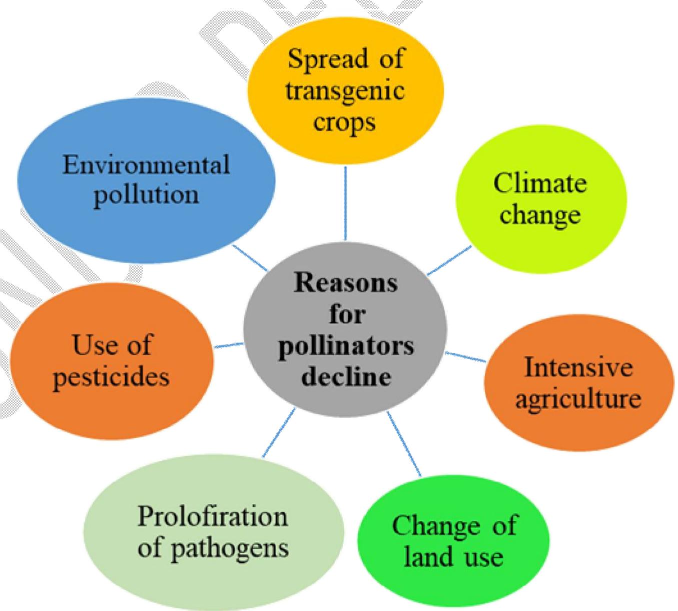

Fig .2 Reasons for declining of pollinators

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3. MAINTENANCE IN ECOSYSTEM

3.1 Planting Bee-Friendly plants

By measuring the different aspects of bee activity, such as honey stores, brood area, egg laying, and pollen stores, there was plenty of food available for the bees, known as ~~Bee~~ 'bee flora', in the month of April, and the bees were active and thriving. As the months progressed, especially by June, these values decreased to zero, which is called ~~Dearth~~ 'dearth period'. This decline was due to shortage of food sources for the bees [35]. Orchards, surrounded by diverse ~~landscapes with various~~ habitats like croplands, grasslands, and woodlands, ~~which~~ support more and unique resources for wild bees. These varied habitats had different types of flowers that bloom at different times, ensuring a continuous supply of food for bees throughout their foraging periods [36]. Plants with different colours, shapes, and sizes ~~to~~ attract a diverse range of bee species. ~~Avoid using pesticides and herbicides, as they can harm bees.~~

3.2 Provide nesting site

Providing nesting sites for bees involves creating suitable environments where bees can build their nests and lay eggs. This is particularly important for solitary bees, which do not live in colonies and need individual nesting spaces [37]. One simple way to build nesting sites is to leave patches of bare ground, as some ground-nesting bees prefer this for their nests. Additionally, installing bee-hives can be beneficial. These are structures with small cavities that mimic natural nesting sites, providing shelter for solitary bees [38]. By incorporating these elements into gardens or outdoor spaces, individuals can support bee populations by giving them safe and suitable places to nest and reproduce.

3.3 Use of safe pesticides

Synthetic pesticides are a key factor in the decline of bee populations. Botanical biopesticides could be a good substitute for synthetic pesticides in protecting plants ~~due to~~because of their high selectivity and quick break down ability ~~quickly~~ in the environment. In some cases, these biopesticides can harm bees, causing both lethal and sublethal effects, but these effects are less severe compared to those caused by synthetic pesticides [39]. Anethole and lemongrass oil showed promising control of Varroa mite, which is a parasite on bees, and appeared relatively safe for both honey bee larvae and adults. It found that the gene related to detoxification in bees was not affected by the treatments [40]. Continuous release of oregano oil was highly effective, achieved a 97.4% control rate for varroa mites with minimal impact on bee mortality. Bees are more active during the day, especially when temperatures are warmer. Spraying pyrethroids on flowering crops, ~~during~~ particularly when ~~honey~~bees are less active as in the early morning or late evening, may lead to unreported bumblebee deaths. But this is a big concern, when spraying pesticides in March or April, as it can harm bumblebee colonies during the time when queens are starting new colonies. It is important to take steps to protect bumblebees during these times and be careful with the choice and timing of pesticides. Insecticides with more selective mode of action, which are engineered to target specific pests and limit harmful effects to beneficial arthropods, have recently become available for control of many potato pests. When using pesticides, checking the guidelines of label Environmental Hazard section for safeguarding bees is important [41].

3.4 Use of ~~Genetically~~ genetically modified crops

By examining data from 1994 to 2017, proteins and traits from these transgenic crops, including protease inhibitors, Cry or VIP toxins, RNAi, and herbicide tolerance, neither negatively affected honey bee survival nor exhibited sublethal effects in controlled conditions. There is no evidence that consuming transgenic pollen from these crops contributes to CCD (Ricroch *et al.*, 2018). When honeybees were exposed to pollen from genetically modified cabbage containing insecticidal proteins (Cry1Ba3), there were no significant differences in pollen consumption, survival, weight, midgut enzyme activity, and detoxification enzyme which shows that the Cry1Ba3 cabbage pollen is unlikely to have harmful side~~-~~-effects on honeybees [42]. Similarly, exposure of bumble bees to two *Bacillus thuringiensis* (*Bt*) formulations (*kurstaki* and *aizawai*) at recommended field rates did not reduce survival when applied dermally or via treated pollen [43].

3.5 Raising ~~Awareness~~ awareness among the growers and consumers

Educating and raising awareness about the importance of bees is crucial for fostering a sense of responsibility towards their well-being and the health of ecosystems. Using social media platforms to share interesting facts, info graphics, and articles about bees by highlighting their importance in maintaining biodiversity and supporting food production is a good option to spread awareness. Participating in or organizing events and exhibitions focused on how urbanization and changes in land use contribute to the loss of natural habitats for bees is also necessary [44]. Celebrating ~~May~~ 20th May as World Bee Day is dedicated to raising awareness about the importance of bees. ~~Use~~ One can use this occasion to organize events, workshops, and educational activities in ~~your~~ his/her community [45]. In many developing countries, small-scale farmers rely on the natural and spontaneous transfer of pollen from male to female flower parts without intentional human intervention, often unaware of its economic value. Through the factor of production method, a form of figuring out how much honey bees contribute to farming by looking at the resources and efforts involved in pollination. It helps us to understand the economic value of bees in making crops grow better. ~~and~~ It was found that bee pollination significantly enhances crop yields and quality, with nearly 40% of the annual crop value attributed to this service, predominantly provided by feral bees [46]. Farmers ~~applied~~ applying pesticides, particularly pyrethroids and organophosphates, at an average of 2.9 kg/ha per crop season showed threats to health and the environment, where~~,~~ both farmers and retailers often did not adopt proper safety measures due to lack of incentives. It shows that training programs and awareness initiatives~~,~~ delivered through media channels like radio, television, and posters~~,~~ could improve safety practices among farmers and retailers regarding pesticide handling [47].

3.6 ~~IPPM (~~Integrated Pest and Pollinator Management~~)~~ (IPPM)

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Integrated pest management (IPM) is a well-established decision support system that prioritizes employing various approaches to manage pest populations. Integrated Crop Pollination (ICP) is a relatively new approach cognate to IPM~~,~~ but tailored for pollinators. It stresses the amalgamation of various tactics to ensure consistent and sustainable crop pollination [48]. The concept of Integrated Pest and Pollinator Management (IPPM) proposes incorporating pollinator management into IPM practice. Alternatively, it involves integrating IPM with crop pollination management through coordinated, ecology-based strategies to mitigate the impacts of both pests and pollinators [49]. The main aim of IPPM is to harmonize the control of pests, including insects, weeds, and diseases, with the preservation and promotion of beneficial species such as pollinators, predators, parasitoids, and entomopathogens [50].

Expanding the IPPM concept involves managing agroecosystem functions influenced by pests, natural enemies, and pollinators, where arthropods play a central role in each function. The significance of co-management of pest and pollinator is highlighted by the fact that certain species can fulfill multiple roles, such as predation, pollinator, and herbivory. For instance, larvae of hoverflies ~~larva~~ act as predators while adults serve as pollinators, and certain bee species like *Trigona spinipes* (Fabricius) can function as either pollinators or pests depending on the specific crop type [51]. The formulation of IPPM strategies involves combining measures that offer complementary or synergistic advantages for crop yield, while simultaneously addressing potential conflicts such as ecosystem 'disservices'.

Fig .3 IPPM Pyramid

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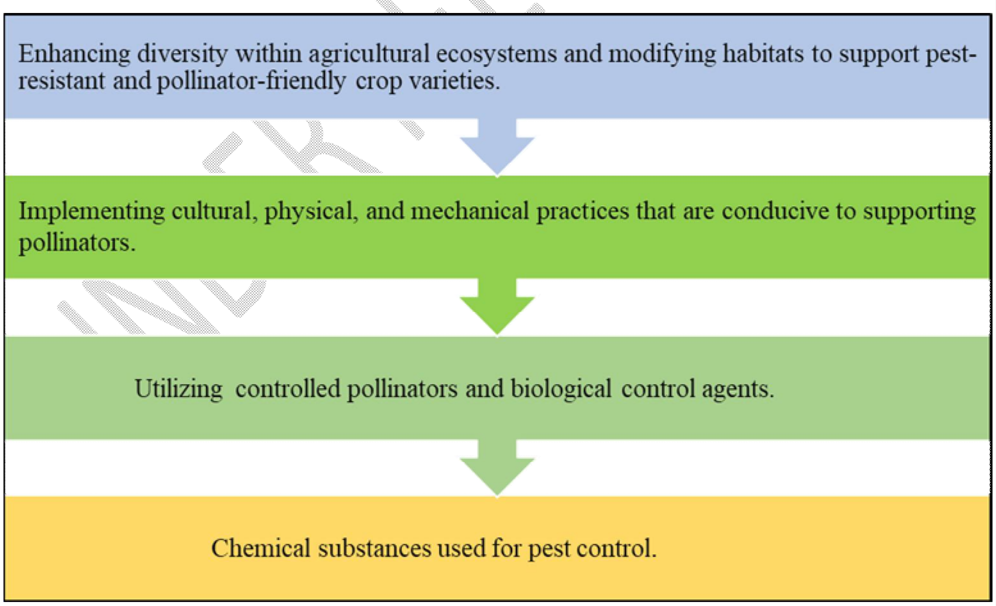

3.6.1.Benefits of IPPM:

- Enhanced focus on sustainable crop pollination and pest control [52]
- Precise targeting of pests leads to broader environmental benefits and sustainable ecology [53]

- Minimized trade-offs with increased co-benefits for both pest and pollinator management [54]
- Reduced exposure of pollinators to harmful pesticides, fostering a more pollinator-friendly environment [15]
- Improved crop productivity through selective pest reduction and enhanced pollination ~~(~~[55~~)~~]

3.7 Pollination Information Management System (PIMS)

A number of national level organizations focused on the conservation and sustainable use of pollination services for sustainable agriculture have teamed up with the Food and Agriculture Organization (FAO) to build the Pollination Information Management System. The purpose is to provide farmers, farm advisers, and land managers with up-to-date, reliable information on managing pollination services of important crops worldwide.

4. CONCLUSION:

To maintain the health and sustainability of ecosystems, conservation of pollinators is important. Pollinators, including bees, butterflies, birds, ~~and~~ bats, etc., play a crucial role in the reproduction of flowering plants, which in turn sustains biodiversity. The decline in pollinator populations due to factors such as habitat loss, pesticide use, climate change, and diseases poses a significant threat to global food security, economic aspects, and ecosystem stability. Urgent conservation efforts are required to protect and restore pollinator habitats, ~~reducing~~ reduce the use of harmful pesticides, and raise awareness about the importance of these vital species. Collaborative initiatives involving government, communities, and organizations are essential to ensure the long-term survival of pollinators and the ecosystems they support. Ultimately, the conservation of pollinators is not just an environmental imperative but also a key component of securing a resilient and thriving planet for future generations.

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